

CARBON NANOTUBE FIELD EMITTERS FOR MINIATURE MASS SPECTROMETERS AND NANOKLYSTRONS

Interim Report

JPL Task 1018

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A. OBJECTIVES







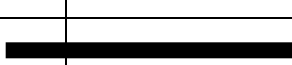
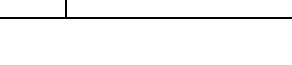
This is a seed proposal to develop ordered, grid-integrated carbon nanotube (CNT) field-emission arrays for use as ionizers in miniature mass spectrometers and as a cold cathode in the nanoklystron, a microminiature source of terahertz radiation. Both of these devices are essential components for future lightweight, low-cost, robotic space missions.

Objectives of this proposal are to 1) fabricate dense, unidirectional carbon nanotubes with monolithic integrated grids, 2) test the field emission characteristics of these nanotubes in a generic emission test system, built using this grant, which can also be used for assembling and packaging nanotubes with micro devices, and 3) demonstrate the use of these new emitters in prototype compact gas ionizers and nanoklystrons. The proposal represents a multidisciplinary effort spanning four different research groups at JPL and Caltech, drawing from and merging their combined strengths and device needs.

B. PROGRESS AND RESULTS

Significant progress has been made in achieving the goals initially set out. Table 1 below compares the original task implementation plan with the tasks accomplished so far (■ indicates the originally-planned milestone period, and ■ indicates the accomplished milestones in this reporting period). From the table, it is clear that the project is well on course in this reporting period (that is, the first six months), making progress faster than initially expected. We have finished first field emission tests of single-walled nanotubes (SWNTs) fabricated at Caltech (see Figure 1), and multi-walled nanotubes (MWNTs) fabricated at JPL (see Figure 2).

Table 1. Status of the project with respect to the original task implementation plan

Tasks	First 6 Months	Second 6 Months	Third 6 Months
SWNT and MWNT growth on plain and patterned substrates			
Field emission test system construction			
Fabrication of stand-alone grids for initial testing			
First field emission tests			
Integration of grid on SWNTs and MWNTs			
Second field emission tests			
Possible assembly of nanotubes into a Nanoklystron prototype			
Designing of field emission source for miniature gas ionizers			

1. Science Data

Figure 3 shows a sketch of the measurement setup that was used for field emission testing. Figures 4 shows cumulative field emission graphs for all the samples. Field emission phenomenon is defined by the Fowler-Nordheim equation: $\ln(I/V^2) = \ln(a) - b/V$, where I is the emission current (in A), V is the biasing voltage (in V), a and b are the F-N parameters, which qualify the field emission characteristics of a given sample. Figure 5 shows comparative Fowler-Nordheim (F-N) plots for all the samples. Linearity of the curves proves field emission. By fitting the F-N curves, parameters a and b of the F-N equation have been calculated. The individual results breakdown is given below (Note: Threshold voltage mentioned below is tube density dependent, as it gives a macroscopic value of the total measured current over the entire emission area).

(1) SWNT (Caltech): Tube diameter ~ 5 nm; threshold voltage for 1 mA/cm^2 emission density $\sim 18 \text{ V/}\mu\text{m}$; maximum measured current density $\sim 7.4 \text{ mA/cm}^2 @ 30.7 \text{ V/}\mu\text{m}$; F-N parameters, $a = 4.11 \times 10^{-6}$, $b = 3054$.

(2) MWNT (JPL) sample 1: Tube diameter ~ 50 nm; threshold voltage for 1 mA/cm^2 emission density $\sim 2.3 \text{ V/}\mu\text{m}$; maximum measured current density $\sim 25.5 \text{ mA/cm}^2 @ 3.6 \text{ V/}\mu\text{m}$; F-N parameters, $a = 3.44 \times 10^{-6}$, $b = 3349$.

(3) MWNT (JPL) sample 2: Tube diameter ~ 50 nm; threshold voltage for 1 mA/cm^2 emission density $\sim 3.8 \text{ V/}\mu\text{m}$; maximum measured current density $\sim 32.3 \text{ mA/cm}^2 @ 6.25 \text{ V/}\mu\text{m}$; F-N parameters, $a = 1.98 \times 10^{-6}$, $b = 5257$.

2. Other Results

As planned in the original proposal, a multipurpose ultra-high vacuum (UHV) chamber was constructed for field emission testing as well as for the nanoklystron device assembly and testing. Figure 6 shows a photograph of the test chamber, which is currently being used for field emission testing.

C. SIGNIFICANCE OF RESULTS

This task is in the process of developing high-current-density, low-threshold-voltage field emission sources for a nanoklystron (a novel source of terahertz radiation) and a miniature mass spectrometer (to chemically analyze complex environments and safeguard astronaut health through environmental monitoring). Both of these instruments are of great significance for future NASA missions.

The results indicate that low-emission threshold voltage is already possible and can be further improved by adding extraction grids. Also, the measured current density is already suitable for preliminary tests with the miniature mass spectrometer. However, the emission density is still less than that required to realize a high-power-output nanoklystron. But adding focusing grids and improving the planarity of emission tips is anticipated to help achieve this goal.

D. FINANCIAL STATUS

The total funding for this task was \$156,500, of which \$78,230 has been expended.

E. PERSONNEL

Wei Lien Dang (SURF student from Caltech)

F. PUBLICATIONS

- [1] H. Manohara, P.H. Siegel, C. Marrese, B. Chang, J. Xu, "Fabrication and Emitter Measurements for Nanoklystron: A Novel THz Micro-Tube Source," Third IEEE International Vacuum Electronics Conference - IVEC 2002, Monterey, CA, April 23-25 (2002)

G. APPENDIX: FIGURES



Figure 1. SWNTs from Caltech

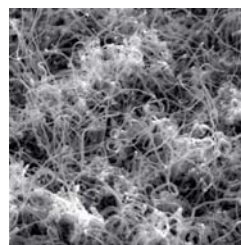


Figure 2. MWNTs from JPL

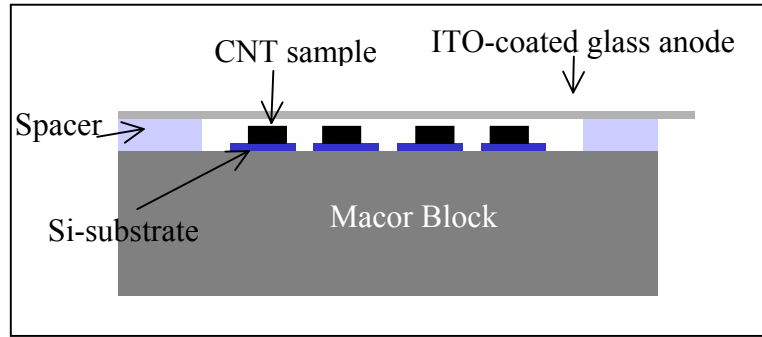


Figure 3. Field emission measurement setup

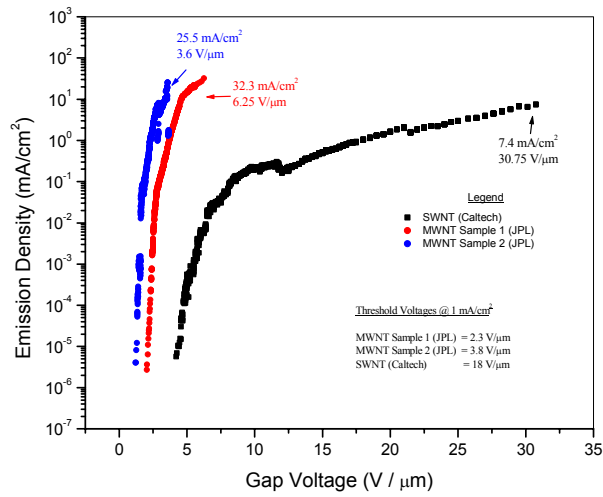


Figure 4. Normalized field emission curves for SWNTs and MWNTs

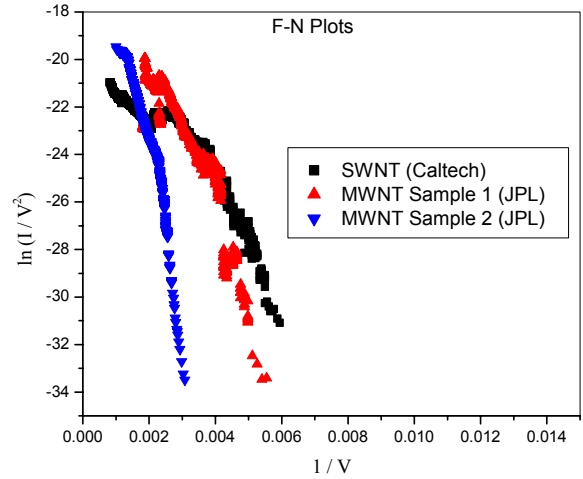


Figure 5. Fowler-Nordheim curves for SWNTs and MWNTs

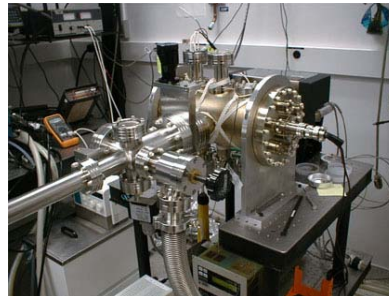
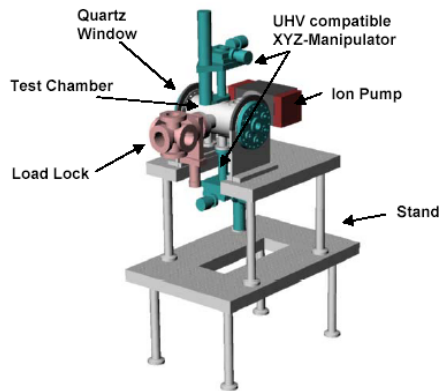


Figure 6. UHV chamber for field emission testing and for nanoklystron assembly and testing